Dynamic and Automatic Interworking between Personal Area Networks using Composition

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Abstract— **Next generation communication networks will be characterized by the coexistence of multiple technologies and user devices in an integrated fashion. The increasing number of devices owned by a single user will lead to a new communication paradigm: users owning multiple devices that form cooperative networks, and networks of different users that communicate with each other, e.g., acquiring Internet access through each other. In this communication scenario no user intervention should be required and technology should seamlessly adapt to the user's context, preferences, and needs. In this paper we address one of those scenarios, interworking between Personal Area Networks, using legacy technologies and the Ambient Network and Network Composition concepts, herein explained. We argue that new functionalities should be introduced to enable effortless use of legacy technologies in such dynamic and heterogeneous environments.**

Index Terms— **Ambient Networks, Network Composition, Interworking, Personal Area Networks, Beyond 3G.**

I. Introduction

A relevant feature of Beyond 3G (B3G) networks will be that users carry several different devices forming small moving networks and, among these, Personal Area Networks (PANs) will be common. Additionally, PANs of different owners will cooperate with each other, in order to, for example, use the Internet access that one of them is able to provide, share files, etc.

Nowadays, this communication scenario is not feasible without manual configurations and offline negotiation between users. Bluetooth [1] and IEEE 802.15 [2,3] allow plug&play creation of PANs at link level. Besides, Bluetooth can enable interworking between PANs if the scatternet concept defined in [1] (communication between Bluetooth piconets) is used along with bridging or routing implemented at IP layer. Though, such a bridging and routing functionality requires user intervention in order to establish communication between PANs. On the other hand, online negotiations between devices and networks, taking into account user needs, preferences, his location, and the kind of devices he is using at each time, is not possible.

The IST Ambient Networks Project [4,5] is studying solutions for the cooperation between networks in a plug&play manner, based on two innovative concepts, Ambient Network (AN) and Network Composition. The purpose is to allow network interworking on-the-fly and transparent to the user. According to the AN concept, every device and network (e.g., sensors, laptops, PANs, etc.) is treated as an AN, and the network is the primitive building block of the architecture, allowing all types of networks and devices to be composed into larger networks. Moreover, end users, who increasingly own multiple devices supporting different communication interfaces and forming small networks, are treated as operators of low-complexity networks.

While a lot of effort needs to go into the development of the theoretical concepts, it is also important to verify the composition approach by concrete examples. In this paper we illustrate interworking between PANs using existing technologies and the new innovative concept of Network Composition, allowing plug&play internetworking.

The remainder of this paper is organized as follows. The AN and Network Composition concepts are described in Section II. The example scenario "Interworking between PANs" is presented in Section III. In Section IV and V this scenario is described using legacy technologies and the Composition Framework, respectively. Finally, in Section VI the advantages arising from Network Composition are summarized, and in Section VII conclusions are drawn.

II. The Ambient Network and Network Composition Concepts

An AN can be any network, provided it has an identity, an Ambient Control Space (ACS), and supports a specific control interface, the *Ambient Network Interface* (ANI). The ACS comprises the control plane functions of an AN, and has a modular structure, with independent – while interworking – *Functional Areas* (FAs) for each control plane function, e.g., Connectivity Functional Area (Cn-FA), Composition Functional Area (C-FA), etc., as shown in Figure 1. An FA may, for instance, be implemented by means of a daemon process responsible for the negotiation

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and realization of a part of a so-called Composition Agreement (see below) related to a specific issue, e.g., Connectivity, Quality of Service (QoS). Beyond this, there are a few prescriptions how the ACS is realized, for example, which functionality it supports, whether it is implemented in a distributed or centralized fashion; the functional split considered inside the ACS is explained in [5].

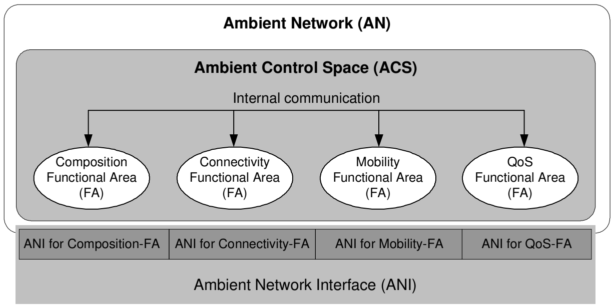

Figure 1. AN's Ambient Control Space architecture

ANs can compose with each other. Composition allows dynamic and instantaneous interworking of networks on the control plane, in addition to the data plane cooperation possible today. Control plane internetworking goes beyond basic addressing and routing by encompassing, for example, mobility, security, and QoS control. When ANs compose, they communicate across the ANI to negotiate a cooperation agreement, called Composition Agreement (CA), which includes the joint resources, the policies that they must follow to coordinate their ACSs, and the services provided to each other; the CA is defined by the set of FAs interested in participating in the current Composition.

The result of a composition can be a new composed AN that manages all logical and physical resources contributed by each constituent AN. It has its own ACS controlling all its resources, and communicates to the outside with its own identifier and via its own ANI. Composition however does not necessarily result in a new AN. In this case, resources belonging to constituent ANs stay under the control of each individual AN, and ANs just interwork based on the negotiated CA. Whether a new composed AN is created or not depends on the negotiation process, and may be influenced by different aspects, such as trust relationship between composing ANs and policies. Composition is a recursive process; it does not matter whether the composing ANs are themselves already the result of a composition.

The Generic Ambient Network Signaling (GANS) is the open base set of protocols enabling signaling exchange between FAs via the ANI. It is important to emphasize that GANS does not replace existing or de-facto standard protocols (e.g., used to exchange routing information or for mobility support). GANS is used to exchange information currently not sufficiently covered by generally accepted protocols, such as Service Level Specification (SLS) negotiation, capability exchange, and CA negotiation. The GANS protocol is currently being developed in the Ambient Networks project.

The Composition Framework defines a set of rules and steps, orchestrated by the Composition Functional Area, which schematically look as follows. After the discovering phase, managed by Connectivity-FAs, ANs decide, possibly based on policies, under what conditions composition is desirable. Then an authentication and authorization phase follows. Subsequently, the ANs negotiate the CA; they agree on joint resources and services provided to each other, for example. Next, a realization phase occurs. A new composed AN may be created by selecting an ID, bringing up the common ACS and enabling the common ANI, and the needed actions and configurations are performed to execute the negotiated CA.

A more detailed description of the aforementioned concepts: AN, ACS, FAs, ANI, Composition Framework and CA, can be found in [5,6,7,8].

III. SCENARIO: INTERWORKING BETWEEN PANS

This section presents the example scenario, Interworking between PANs. It should be realized that several technical solutions are available, and only one of them is considered below. Moreover, many technical details need to be considered when setting up such a system, although only a subset is highlighted here.

A. *User Scenario Description*

Anne and John work for different companies and are working together in a common project. Today, John has a meeting with Anne in her office. While on journey to Anne's office, he uses his laptop to access the Internet. The connection is made through UMTS, provided by his mobile phone, based on a relation previously established between these devices, forming John's PAN (PAN-J).

Anne also has a PAN that enables exchange of information between her Personal Digital Assistant (PDA) and her laptop. The laptop has Ethernet access to the Internet, which is not extended to the PDA. When John arrives to Anne's office, his PAN detects Anne's PAN (PAN-A), and he is informed of this. Then, he triggers his PAN to associate with Anne's PAN, so that they could share some files, and John can benefit from the Internet access offered by PAN-A. After successful establishment of the interworking with Anne's PAN, John may decide for the time being not to use the UMTS connection anymore. This scenario is shown in Figure 2.

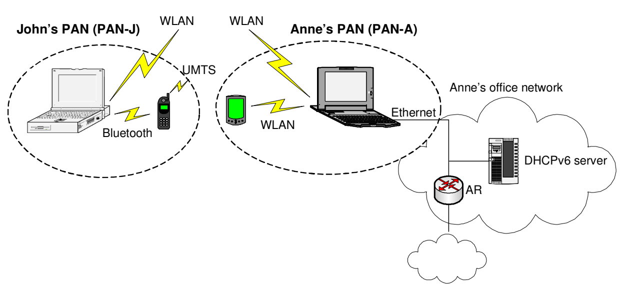

Figure 2. Interworking between PANs

B. *Technical Description*

The scenario in Figure 2 presents two PANs composed of two devices with different capabilities (e.g., network interfaces, CPU). Communication between devices within PAN-J is accomplished using the Bluetooth PAN Profile [1], where the mobile phone acts as a bridge between the Bluetooth network and the UMTS network that provides Internet access [9]; within PAN-A, WLAN technology is used, with both PDA and laptop Network Interface Cards

(NICs) configured by the user in ad-hoc mode [10]. Communication between PANs is carried out using WLAN technology. Internet Protocol version 6 (IPv6) is used, and all devices are pre-configured to automatically acquire an IP address and DNS server(s) address. Furthermore, PAN-A has access to a DHCPv6 [11] server, running in Anne's office network, and to an Access Router (AR) providing Internet access. We assume that both PANs have been previously created, either manually or automatically using the approach described in [12].

IV. INTERWORKING BETWEEN PANS USING LEGACY TECHNOLOGIES

This section addresses the realization of the scenario shown in Figure 2, using legacy technologies. In this case, offline negotiation between John and Anne and manual configurations are needed, so that PAN-A can provide Internet access to PAN-J. John is not able to access Anne's office Intranet services (e.g., web server, printing), since it is assumed that user authentication is required. A service-independent security solution could be considered as well to restrict unauthorized access to the corporate network, and to ensure that all packets originated from John's PAN not destined to either Anne's PAN or the corporate AR are discarded. The steps performed towards Interworking between the PANs are:

1. PAN-A sends beacon frames announcing itself to the outside. The beacons contain the SSID (System Service ID) of the WLAN in ad-hoc mode.
2. Anne informs John that she can offer Internet access free of charge through her PAN.
3. John configures his laptop's WLAN interface in ad-hoc mode in order to detect PAN-A.
4. Anne configures her laptop as a bridge between the WLAN and Ethernet link, so that PAN-J can acquire the needed connectivity parameters, e.g., global IPv6 address.
5. The laptop of PAN-J receives PAN-A beacon frames through its WLAN interface, and John is informed by his laptop about the presence of PAN-A.
6. Using IPv6 link-local addresses, PANs perform mutual authentication based on certificates, assigned by a trusted third party.
7. The laptop in PAN-J starts receiving Router Advertisement messages [13], sent out by the AR inside Anne's office network, and a global IPv6 address is automatically configured according to the procedure defined in [14].
8. The laptop in PAN-J is able to communicate with the DHCPv6 server in Anne's office network (since the laptop of PAN-A is acting as a bridge), in order to retrieve other information, such as DNS server address, ending up the configuration process.
9. After associating with PAN-A, John decides to switch from UMTS to WLAN access, offering broader bandwidth, and free of charge service.
10. John can now share files with Anne and benefit from Internet access provided by Anne's PAN. He may decide not to turn off the UMTS connection.

V. INTERWORKING BETWEEN PANS USING THE COMPOSITION FRAMEWORK

When the Composition Framework is applied, user intervention is minimal. John is interested in getting the broadest bandwidth Internet access at the lower price. Having this in mind, and using a specific application, he defines a user profile in advance, where the high-level policies that must be fulfilled when performing compositions with other ANs are settled; the aforementioned statement "get broadest bandwidth at lower price" is an example. Subsequently, that application translates this profile into a set of policies used by C-FA to perform compositions automatically. It is important to note that the user profile is defined once. Afterwards, the set of policies derived from it are used in each concrete composition scenario to decide whether the current AN should compose or not with the peer AN able to do it. Hence, user involvement is limited to the definition of the user profile. After that, everything can happen automatically.

In order to illustrate the Composition process, Table 1 describes the possible steps towards interworking between PANs using the Composition Framework defined in Section II. Both PANs are considered ANs, and no new composed AN is created. We assume that the advertisement messages sent by the PANs contain just their identifiers. The description below considers a conceptual analysis and does not take into account implementation specific issues; these are left for further study in the Ambient Networks project.

Table 1. Composition Procedure

Composition Framework	**Detailed Procedures** (From PAN-J point of view)
AN Discovery	1. PAN-J moves towards PAN-A. Both PANs are sending out advertisement messages containing their identifiers (AN_ID). 2. Connectivity-FA of PAN-J (Cn-FA_J) detects advertisement messages of PAN-A, and informs its Composition-FA (C-FA_J) about this.
AN Authentication	3. C-FA_A requests authentication from C-FA_J. 4. C-FAs of each PAN perform mutual authentication using, for example, certificates assigned by a third party.
CA Creation	5. After the successful completion of the authentication phase, C-FA_A, acting as a provider from the Internet access service standpoint, gets a locally stored off-the-shelf CA; this is a standard CA defining the services the owner of PAN-A (Anne) is willing to offer to other ANs, in this case Internet access. User intervention is needed concerning the selection of these services.

CA Negotiation	6. C-FA_A starts CA negotiation by sending the off-the-shelf CA as a first proposal. The negotiation is performed automatically and is governed by the policies settled a priori by the owners of the PANs, e.g., just start CA Negotiation if peer AN is qualified by a pre-configured "positive list". 7. C-FA_J receives that proposal, and by analyzing it, finds out that peer AN offers Internet access service. Moreover, since there is a connectivity related policy installed in PAN-J, the process is transferred to Cn-FA_J. 8. Cn-FA_J analyzes the CA from the connectivity viewpoint and compares the connectivity services offered with the one settled by the policy previously defined. 9. Cn-FA_J finds out that the current AN is suitable to create a composition and informs C-FA about it. 10. Multiple negotiation rounds may be involved. Though, in this case, C-FA_J agrees with the first proposal and sends back a confirmation accepting it.
CA Realization	11. C-FAs synchronize in order to start the realization phase, and the process is passed to Cn-FAs. 12. Cn-FAs execute the necessary procedures to have PAN-J accessing the Internet through PAN-A: a) Cn-FA_A configures Anne's laptop as a bridge between the WLAN and the Ethernet link. b) Legacy technologies are used to autoconfigure the connectivity parameters – global IPv6 address and DNS server address – using the same procedure described in Section IV (steps 7–8). 13. Each C-FA informs the corresponding user that the composition is established (henceforth, PAN-J uses the Internet access provided by PAN-A). 14. After composing with PAN-A, Cn-FA_J switches from UMTS to WLAN access, according to the connectivity policy defined by the user.

VI. New Functionalities and Composition Advantages

In order to achieve Network Composition with current technologies, a set of new functionalities needs to be provided. Below we describe the main functionalities of ANs required by current technologies to achieve composition for the presented scenario:

- *Capacity for automatic configuration of resources (e.g., wireless cards, devices, etc.)*. ANs are able to automatically configure resources in order to adapt to the user context (devices in use, location, time), preferences and needs.
- *Capacity to understand resources' capabilities* (e.g., ability to know that a UMTS interface can provide Internet access), so that dynamic and automatic negotiation can be achieved.
- *Automatic Decision Capability*. Considering, for example, several Internet access options (e.g., UMTS and Ethernet) an automatic and adjustable mechanism is needed, so that the interface that best suits the user needs, according to some criteria (e.g., bandwidth, cost), is selected.
- *Automatic and dynamic negotiation capabilities*. ANs are able to perform online negotiations, e.g., using the GANS protocol. During these negotiations, several proposals may be made, and ANs are able to select the best proposals according to, for example, internal policies possibly pre-defined by the user.
- *Automatic realization of negotiation*. The negotiated proposal is used to create the required run-time rules and other configuration information to provide transparent deployment of new composition services and resources.
- *Automatic recovery from failures*. Current technologies are limited with respect to this feature, as far as intelligence is concerned. Regarding the scenario in Figure 2, if the Ethernet link breaks down, PANs can automatically renegotiate the established Composition Agreement, so that the UMTS connection (of PAN-J) can be used to access the Internet.

Using the scenario described in this document, and the new functionalities mentioned above, we can identify the following advantages in the establishment of a composition between PANs:

1. Current technologies require user intervention in the configuration process. With composition, the connectivity issues are automatically and transparently handled by the Connectivity-FAs without user intervention.
2. Negotiation processes generally require user intervention. Conversely, the composition process addresses this kind of negotiation in an automatic manner with minimal or no user intervention.
3. Recovery from failures is not always achieved easily and automatically today. The dynamic and automatic procedures involved in composition allow "fast" recovery from failures.
4. The establishment of compositions between PANs enables innovative business models. Each user may have economic benefits from the establishment of relations with other users' networks (e.g., one PAN may offer Internet access to other PANs billing them for that).

Table 2 presents a comparison how the steps above-mentioned are accomplished when legacy technologies are used alone, or in conjunction with the Composition Framework.

Table 2. Comparison between Legacy Technologies and Composition Framework

Actions	Only Legacy Technologies	With Composition Framework
Service Advertisement	Through user–user communication	Automatic
Negotiation	Through user–user communication	Automatic (user intervention required to define the policies governing the negotiation)
Configuration of resources	Manual (may involve expertise in networking)	Automatic
Selection of the proper network access	Manual	Automatic (possibly based on policies)

VII. FURTHER WORK

In the exploration of the scenario, QoS and Mobility issues were postponed for further work. The introduction of the QoS-FA in order to handle the negotiation of SLSs between ANs, and Mobility-FA to manage vertical and horizontal handovers, will be considered. Additionally, the establishment of secure channels to exchange signalling information between composing ANs and an extension of the current scenario involving more than two PANs behaving as clients and/or providers might be considered. On the other hand, implementation issues such as scalability analysis and signalling overhead were not considered, and will be analysed in the future within the Ambient Networks project.

VIII. CONCLUSION

In this paper we have presented an example scenario, Interworking between PANs, from both the legacy technologies and the Composition Framework perspectives. This communication scenario is envisioned to be common in future B3G networks, where users will own a multitude of network devices forming cooperative ad-hoc networks, and will be considered as operators of special low-complexity networks. We presented the functionalities required to pave the way towards Network Composition, which is proposed as a new innovative solution that allows going a step further with respect to what can be achieved today with legacy technologies. Using this solution, such a cooperative communication scenario can be established in a plug&play manner based on dynamic and automatic negotiations between networks, and according to the user preferences and needs.

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